AD-A230 179

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-01...

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 27, 1990	FINAL - May 1, 1988 - September 30, 1990

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
ADAPTIVE COMPUTATIONS FOR PARTIAL DIFFERENTIAL EQUATIONS GOVERNING ADVECTIVE FLUID FLOWS	N00014-88-K-0370 (WYOM 5/331-3)

6. AUTHOR(S)

Richard E. Ewing (Principal Investigator and Compiler)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Center for Mathematical Modeling (now - Institute for Scientific Computation) University of Wyoming Box 3036 Laramie, WY 82071	N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
University of Wyoming Contracts and Grants Accounting P.O. Box 3355 Laramie, WY 82071	N/A

11. SUPPLEMENTARY NOTES (Abstract continued from Block 13 below) (applying conjugate-gradient and conjugate-residual methods to solve the large, sparse linear systems arising from the discretization of the governing equations), and the exploitation of parallel and vector computer architectures.

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Unclassified/Unlimited	

13. ABSTRACT (Maximum 200 words) We developed improved approaches to the numerical simulation of highly advective fluid flows using adaptive computational schemes. (Applications include heat and mass transfer in flowing fluids, reaction-diffusion phenomena of combustion, bubbly and multiphase flows, underwater explosions, and electrochemistry). Solutions to the equations governing these flows commonly exhibit highly localized features -- steep moving fronts, moving boundaries, unstable interfaces -- not captured by standard numerical techniques with acceptable accuracy and computational cost. We developed adaptive techniques in which computational degrees of freedom are allocated according to qualitative properties of the equations being solved, to efficiently enhance local resolution.

We focused on adaptive gridding methods (implementing adaptive local gridding algorithms, in which a code automatically refines the finite-element or finite-difference grid in zones needing temporarily increased numerical resolution), front-tracking algorithems (generalizing a sophisticated front-tracking code first developed for strictly hyperbolic systems of conservation laws, based on the numerical tracking of an interface via sequences of Riemann problems), development of efficient iterative schemes and preconditioners for large linear systems (continued in Block 11 above)

14. SUBJECT TERMS		15. NUMBER OF PAGES
adaptive grid refinement techniques, multiphase flow, conjugate gradient methods, front-tracking methods, convection-diffusion equations		11
		16. PRICE CODE N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

DTIC ELECTE JAN 0 4 1991

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements*.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	PR	- Project
G	- Grant	TA	- Task
PE	- Program Element	WU	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of ...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

> DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
> DOE - See authorities.
> NASA - See Handbook NHB 2200.2.
> NTIS - Leave blank.

Block 12b. Distribution Code.

> DOD - Leave blank.
> DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
> NASA - Leave blank.
> NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e. UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limit to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

OFFICE OF NAVAL RESEARCH
FINAL REPORT
for
1 MAY 1988 THROUGH 30 SEPTEMBER 1990
CONTRACT No. 0014-88-K-0370

ADAPTIVE COMPUTATIONS FOR
PARTIAL DIFFERENTIAL EQUATIONS
GOVERNING ADVECTICE FLUID FLOWS

PRINCIPLE INVESTIGATOR: Richard E. Ewing
Director, Center for Mathematical Modeling
Departments of Mathematics,
Chemical Engineering, and Petroleum Engineering
University of Wyoming

Accesion For

NTIS CRA&I	☑	
DTIC TAB	☐	
U.:announced	☐	
J..stification		

By

Di:t ibution /

Dist		
A-1		

December 1990

96 12 21 090

BRIEF SUMMARY OF RESEARCH

Task 1. Properties of Differential Equation Models

In [18,32,40] we studied stability properties of unstable fluid flow. We presented the effects of the nonlinearities and properties such as bifurcation in [18,36,51]. Stability of multiphase flow was studied in [32]. This gives us insight into the important properties of unstable, bubbly flow.

Special properties and treatment of singularities in the solutions to partial differential equations were presented in [4,39]. Asymptotic behavior of solutions was studied in [12,36]. Properties of hyperbolic conservation laws and non-hyperbolic systems were analyzed in [17,18,36,37,39,52]. Properties of models of various types were considered in [4,62,63].

Finally, unknown parameters must often be determined in various partial differential equation models. Special direct marching methods to treat unknown coefficients in time-dependent problems have been developed in [31,38,65–68,76].

Task 2. Analysis of Numerical Procedures

Numerical properties of the various discretization schemes for the partial differential equation models must also be well understood. Stability and accuracy for finite element methods are studied in [2,6,7,30,35,41,56,70,74], for finite strip methods in [19–21], and for collocation methods in [14,53,54]. Analysis for models for chemically reacting flows is presented in [8,15,35,42,72,75].

Accuracy of fluid velocities is essential in the coupled systems in our models. Mixed finite element methods have been studied in [30,34,42,45]. Mixed methods have been coupled with other techniques in multicomponent and multiphase problems in [16,36,40,50,64,81,84,87]. The degeneracies in the multiphase case cause difficulties in the analysis [16].

Hyperbolic, near hyperbolic, and non-hyperbolic systems were studied in [2,5,33], in connection with convection-diffusion-like problems in [5,54]. Front tracking methods have been analyzed via Riemann problems in [36,39,52]. Hyperbolic equations are also used in inverse methods for seismic prospecting, sonar, nondestructive testing, etc. Extensive work on accuracy of numerical methods for interface conditions was studied in [25,79,89].

Operator splitting techniques [2,3,16,72,81,86] have been presented using modified method of characteristics concepts [2,8,16,43,73,84]. When applied to multiphase problems or problems with nonlinear flux functions, the operator splitting methods also utilize Petrov-Galerkin methods [2,41,73] when the problems are not fully symmetrized by the modified method of characteristics. Extensions of these methods to Eulerian-Lagrangian Localized Adjoint Methods (ELLAM) conserve mass and treat boundary conditions well [29,51,77,86,88].

Full asymptotic error estimates are developed for the difficult coupled systems of partial differential equations in [6,13,42,45]. Superconvergence results for mixed finite element methods along Gauss lines were obtained in [34].

Flow of various fluids through heterogeneous media can be quite unstable, with fingering instabilities. Development of effective parameters to model those instabilities for nonlinear scale-up is considered in [32,78,80,82].

Task 3. Adaptive Local Grid Refinement

A major effort has been concentrated on various aspects of adaptive local grid refinement. Elementwise local refinement techniques were presented in [7,53] for Burgers' Equation. Adaptive techniques that entail error estimators or AI strategies were discussed in [1,7,10,16,48,53].

Purely local refinement techniques which involve data structure trees have been described in [1,10,33]. A more efficient method that requires a simpler data structure is a "patch refinement" technique [3,40,44,46,48,65,71,82]. Aspects of accuracy of the composite grid were considered in [22,23,46,57,61,65] and efficiency of solution in [24,44,46,87]. BEPS and FAC methods are presented and compared in [9,22,28,46,57,65]. Extensions of these concepts to local time-stepping methods appear in [27,60]. Applications of these methods in industrial-level simulators appeared in [22–24].

The application of patch method to follow and resolve moving fluid interfaces is presented in [16,41]. Parallel aspects appeared in [14,55].

Several aspects of front tracking methods have been studied. Riemann problem analyses appeared in [36,39,52] while the complications due to non-hyperbolic systems were studied in [18,39,52]. Combinations with mixed finite element methods are considered in [34,45,47].

Task 4. Computational Considerations

The advent of parallel and vector computer architectures and visualization capabilities are revolutionizing computational considerations. Basic efficiency considerations were discussed in [3,10,47,49,59]. Parallel and vector techniques have been presented in [1,14,19,21,46,55,83], with scheduling analysis in [1]. Many of the local grid refinement techniques have been based upon domain decomposition methods [3,9,12,16,28,41,44,50,80]. The potential for parallelization of the modified method of characteristics was pointed out in several papers and is currently being implemented.

Due to the size and poor conditioning of the systems involved, preconditioned iterative methods are essential for linear solution. Preconditioners are presented for conjugate gradients, conjugate residuals, and domain decomposition methods in [3,9,44,85].

Finally, we have made substantial progress in visualization on our Ardent Titan and our Silicon Graphics workstation. This greatly aids our computational capabilities, allowing us to use the computers in an experimental mode to build intuition.

We emphasize that the combination of modeling, analysis, numerical analysis, and computing skills is essential in addressing the complex and unstable coupled systems of partial differential equations used to model problems of interest to the Navy.

2

REFERENCES

I. PAPERS IN REFEREED JOURNALS

A. APPEARED

1. R.E. Ewing, M.S. Espedal, J.A. Puckett, and R.S. Schmidt, Simulation techniques for multiphase and multicomponent flows, *Communications in Applied Numerical Methods* **4** (1988), 335–342.

2. R.E. Ewing, Finite element techniques for convective-diffusive transport in porous media, *Advances in Water Resources* **11** (1988), 123–126.

3. R.E. Ewing, Large-scale computing in reservoir simulation, *The International Journal of Supercomputer Applications* **24** (1988), 45–53.

4. T. Lowry, M.B. Allen, and P.N. Shive, Singularity removal: A refinement of resistivity modeling techniques, *Geophysics* **54** (1989), 766–774.

5. S. Bahgwat and M.B. Allen, Downstream implicit schemes for advection, *Numerical Methods for Partial Differential Equations* **4** (1988), 315–318.

6. J.H. Bramble, R.E. Ewing, and G. Li, Alternating direction multistep methods for parabolic problems – iterative stabilization, *SIAM Journal on Numerical Analysis* **26** (1989), 904–919.

7. M.B. Allen and M.C. Curran, Adaptive local grid refinement algorithms for finite-element collocation, *Numerical Methods for Partial Differential Equations* **5** (1989), 121–132.

8. R.E. Ewing, Yirang Yuan and Gang Li, Time stepping along characteristics for a mixed finite element approximation for compressible flow of contamination by nuclear waste in porous media, *SIAM Journal on Numerical Analysis* **26** (1989), 1513–1524.

9. R.E. Ewing, Preconditioned conjugate gradient methods for large-scale fluid flow applications, *BIT* **29** (1989), 850–866.

10. C.G. Macedo, Jr., J.C. Diaz, and R.E. Ewing, A knowledge-based system for the determination of activity indicators for self-adaptive grid methods, *Mathematics and Computers in Simulation* **31**, 1989, 431–439.

11. D.B. MacGowan, R.C. Surdam, and R.E. Ewing, The effect of carboxylic acid anions on the stability of framework mineral grains in petroleum reservoirs, *SPE Reservoir Evaluation*, June 1990, 161–166.

12. R.E. Ewing, A Survey of domain decomposition techniques and their implementation, *Special Issue on Supercomputing, Advances in Water Resources* **13** (1990), 117–125.

13. R.E. Ewing, A posteriori error estimation, *Computer Methods in Applied Mechanics and Engineering* **82** (1990), 59–72.

14. M.C. Curran and M.B. Allen, Parallel computing for solute transport models via alternating direction collocation, *Advances in Water Resources* **13**(2) (1990), 70–75.

15. M.M. Stephens and E.D. Morehead, A global element Galerkin/B-spline (GBS) numerical model of electrochemical kinetics, transport, and mechanism for

multi-geometry working electrodes, Part II: Quasi-reversible single sweep voltammetry, *Journal of Electroanalytical Chemistry* **282** (1990), 1–26.

16. H.K. Dahle, M.S. Espedal, R.E. Ewing, and O. Saevareid, Characteristic adaptive sub-domain methods for reservoir flow problems, *Numerical Methods for Partial Differential Equations* **6** (1990), 279–309.

17. E.L. Isaacson and B. Temple, The structure of asymptotic states in a singular system of conservation laws, *Advances in Applied Mathematics* **11** (1990), 205–219.

18. E.L. Isaacson, D. Marchesin, and B.J. Plohr, Transitional waves for conservation laws, *SIAM Journal on Mathematical Analysis* **24** (1990).

19. J.A. Puckett and D.L. Wiseman, The compound strip method for folded plates with connecting elements, *Journal of the Structural Engineering* **117** (1990), ASCE.

20. D.L. Wiseman and J.A. Puckett, Applications of the compound strip method for folded plates with connecting elements, *Journal of Structural Engineering* **117** (1990), ASCE.

21. J.A. Puckett and R.J. Schmidt, Finite strip method for groundwater modeling in a parallel computing environment, *Engineering Computation* **7** (1990), 167–172.

B. ACCEPTED

22. R.E. Ewing, R.D. Lazarov, and P.S. Vassilevski, Local refinement techniques for elliptic problems on cell-centered grids, I: Error analysis, *Mathematics of Computation*, (to appear).

23. R.E. Ewing, R.D. Lazarov, and P.S. Vassilevski, Local refinement techniques for elliptic problems on cell-centered grids, II: Optimal-order two-grid iterative methods, *Mathematics of Computation*, (to appear).

24. R.E. Ewing, R.D. Lazarov, and P.S. Vassilevski, Local refinement techniques for elliptic problems on cell-centered grids, III: Algebraic multilevel BEPS preconditioners, *Numerische Mathematik*, (to appear).

25. J. Sochacki, J.H. George, R.E. Ewing, and S. Smithson, Interface conditions for acoustic and elastic wave propagation, *Geophysics*, (to appear).

26. R.E. Ewing, Application of domain decomposition techniques in large-scale fluid flow problems, *Applied Numerical Mathematics*, (to appear).

27. R.E. Ewing, R.D. Lazarov, and P.S. Vassilevski, Finite difference schemes on grids with local refinement in time and space for parabolic problems, I. Derivation, stability, and error analysis, *Computing*, (to appear).

28. J.H. Bramble, R.E. Ewing, R.R. Parashkevov, and J.E. Pasciak, Domain decomposition methods for problems with partial refinement, *SIAM Journal on Scientific and Statistical Computing*, (to appear).

29. M. Celia, T. Russell, I. Herrera, and R.E. Ewing, An Eulerian-Lagrangian localized adjoint method for the advection-diffusion equation, *Advances in Water Resources*, (to appear).

30. R.E. Ewing, Simulation of multiphase flows in porous media, *Transport in Porous Media*, (to appear).

4

31. R.E. Ewing and T. Lin, A class of parameter estimation techniques for fluid flow in porous media, *Advances in Water Resources*, (to appear).

32. R.E. Ewing, T.F. Russell, and L.C. Young, An anisotropic course-grid dispersion model of heterogeneity and viscous fingering in five-spot miscible displacement that matches experiments and fine-grid simulations, *SPE Reservoir Engineering*, (to appear).

33. T. Lin, J. Sochacki, R.E. Ewing, and J. George, Some grid refinement schemes for hyperbolic equations with piece-wise constant coefficients, *Mathematics of Computation*, (to appear).

34. R.E. Ewing, R.D. Lazarov, and J. Wang, Superconvergence of the velocities along the Gaussian lines in the mixed finite element methods, *SIAM Journal on Numerical Analysis*, (to appear).

35. E.D. Moorhead and M.M. Stephens, A finite element Galerkin/B-spline (GBS) numerical model of electrochemical kinetics, transport, and mechanism for multi-geometry working electrodes: Part II. A study of quasi-reversible linear sweep voltammetry, *Journal of Electroanalytical Chemistry*, (to appear).

36. E.L. Isaacson, D. Marchesin, B.J. Plohr, and J.B. Temple, Multiphase flow models with singular Riemann problems, *Matematica Aplicada e Computacional*, (to appear).

37. E.L. Isaacson and B. Temple, Nonlinear resonance in inhomogeneous systems of conservation laws, *Contemporary Mathematics*, (to appear).

38. D. Isaacson and E. Isaacson, Exact solutions of a linearized inverse boundary value problem, *Inverse Problems*, (to appear).

39. E.L. Isaacson, Global solution of a Riemann problem for a non-strictly hyperbolic system of conservation laws arising in enhanced oil recovery, *Journal of Computational Physics*, (to appear).

II. CHAPTERS IN BOOKS

A. APPEARED

40. R.E. Ewing, Adaptive grid-refinement techniques for treating singularities, heterogeneities and dispersion, *IMA Volume 11 Numerical Simulation in Oil Recovery*, (M.F. Wheeler, ed.), Springer-Verlag, Berlin, 1988, 133–148.

41. H. Dahle, M. Espedal, and R.E. Ewing, Characteristic Petrov-Galerkin subdomain methods for convection diffusion problems, *IMA Volume 11 Numerical Simulation in Oil Recovery*, (M.F. Wheeler, ed.), Springer-Verlag, Berlin, 1988, 77–88.

42. R.E. Ewing, Yirang Yuan, and Gang Li, Finite element methods for contamination by nuclear waste-disposal in porous media, *Numerical Analysis*, (D.F. Griffiths and G.A. Watson, eds.), 1987; *Pitman Research Notes in Mathematics, Series 170*, Longman Scientific and Technical, Essex, U.K., 1988, 53–66.

43. R.E. Ewing, A modified method of characteristics for transport of nuclear-waste contamination in porous media, *Computational Mechanics '88 Theory and Applications* II, (S.N. Atluri G. Yagana, eds.), Springer-Verlag, Berlin, 1988, 50ii, 1–4.

44. R.E. Ewing, Domain Decomposition techniques for efficient adaptive local grid refinement, *Domain Decomposition Methods*, (T.F. Chan, R. Glowinski, J. Periaux, and O.B. Widlund, eds.), SIAM, Philadelphia, Pennsylvania, 1989, 192–206.

45. R.E. Ewing, Yirang Yuan, and Gang Li, A time-discretization procedure for a mixed finite element approximation of contamination by incompressible nuclear waste in porous media, *Mathematics for Large-Scale Computing*, (J.C. Diaz, ed.), in *Lecture Series in Pure and Applied Mathematics* 120, Marcel Dekker, New York, 1989, 127–145.

46. R.E. Ewing and R.D. Lazarov, Local refinement techniques in the finite element and finite difference methods, *Numerical Methods and Applications*, Publishing House of the Bulgarian Academy of Sciences, Sofia, Bulgaria, 1989, 148–159.

47. R.E. Ewing, Computational methods for nonlinear systems of partial differential equations arising in contaminant transport in porous media, *Computational Solution of Nonlinear Systems of Equations*, (E.L. Allgower and K. Georg, eds.), in *Lectures in Applied Mathematics, Series 26*, American Mathematical Society, Providence, Rhode Island, 1990, 151–164.

48. R.E. Ewing, Adaptive grid refinements for transient flow problems, *Adaptive Methods for Partial Differential Equations*, (J.E. Flaherty, P.J. Paslow, M.S. Shephard, and J.D. Vasilakis, eds.), SIAM, Philadelphia, Pennsylvania, Chapter 14, 1989, 194–205.

49. R.E. Ewing, Large-scale scientific computation for distributed systems, in *Distributed Parameter Control Systems, New Trends and Applications, Lecture Notes in Pure and Applied Mathematics*, (C. Chen, E.B. Littman, and L. Markus, eds.), Marcel Dekker, Publishers, New York, New York, 1990, 139–170.

50. R.E. Ewing, R.D. Lazarov, T.F. Russell, and P.S. Vassilevski, Local refinement via domain decomposition techniques for mixed finite element methods with rectangular Raviart-Thomas Elements. *Domain Decomposition Methods for Partial Differential Equations*, (T.F. Chan, R. Glowinski, J. Periaux, and O. Widlund, eds.), SIAM Publications, Philadelphia, Pennsylvania, 1990, 98–114.

51. R.E. Ewing and M.A. Celia, Multiphase flow simulation in groundwater hydrology and petroleum engineering, *Computational Methods in Subsurface Hydrology*, (G. Gambolati, A. Renaldo, C. Brebbia, W. Gray, and G. Pinder, eds.), Springer Verlag, Berlin, 1990, 159–204.

52. E.L. Isaacson, D. Marchesin, and B.J. Plohr, The structure of the Riemann solution for non-strictly hyperbolic conservation laws, *Proceedings of the Second International Conference on Nonlinear Hyperbolic Problems*, Aachen, FRG, March 14-18, 1988; Nonlinear hyperbolic equations – theory, computation methods, and applications, (J. Ballmann and R. Jetsch, eds.), *Notes on Numerical Fluid Mechanics* 24 (1989), Vieweg, Braunschweig, 269–278.

53. M.B. Allen and M.C. Curran, Adaptive collocation for Burgers' equation, *Computational Methods in Water Resources, Vol. 2; Numerical Methods for Transport and Hydrologic Processes, Developments in Water Science, Vol. 36*, (M.

Celia *et al.*, eds.), Southampton, U.K., Computational Mechanics Publications, 1988, 123–128.

54. M.B. Allen and M.C. Curran, An adaptive gridding scheme for solving advection-dominated flows using finite-element collocation, *Computational Mechanics '88: Theory and Applications*, (S. Atluri and G. Yagawa, eds.), Berlin, Springer-Verlag, 1988, 50.iv.1–50.iv.4.

55. M.C. Curran and M.B. Allen III, Parallel computing speedups for alternating direction collocation, *Proceedings, Seventh International Conference on Finite Element Methods in Flow Problems*, Huntsville, Alabama, April 3–7, 1989, (T. Chung and G.R. Kerr, eds.), University of Alabama Press, Huntsville, 1989, 947–952.

B. ACCEPTED

56. R.E. Ewing, Finite element methods for multiphase and multicomponent flows, *Hemisphere – FEMIF-7*, (to appear).

57. R.E. Ewing, P. Jacobs, R. Parashkevov, and J. Shen, Applications of adaptive grid refinement methods, *Proceedings of Fifth IIMAS Workshop on Numerical Analysis*, SIAM, Philadelphia, Pennsylvania, (to appear).

58. R.E. Ewing, B.A. Boyett, and M.S. El-Mandouh, Local grid refinement for reservoir simulation, *Proceedings of the SIAM Conference on Mathematical and Computational Issues in Geophysical Fluid and Solid Mechanics*, SIAM, Philadelphia, Pennsylvania, (to appear).

59. R.E. Ewing, Supercomputing in reservoir simulation, *New Generations Computing in Supercomputing in Engineering Analysis*, Marcel Dekker, New York, New York, (to appear).

60. R.E. Ewing, R.D. Lazarov, and P.S. Vassilevski, Finite difference schemes on grids with local refinement in time and space for parabolic problems. II: Optimal order two-grid iterative methods, *Lecture Notes in Fluid Mechanics*, Vieweg Publishers, (to appear).

III. PROCEEDINGS OF CONFERENCES

A. APPEARED

61. R.E. Ewing and R.D. Lazarov, Adaptive local grid refinement, SPE No. 17806, *Proceedings of 1988 Rocky Mountain Regional Meeting of SPE*, Casper, Wyoming, May 1988, 643–652; and *Proceedings of Fourth Wyoming Enhanced Oil Recovery Symposium*, Casper, Wyoming, May 1988, 87–102.

62. D.B. MacGowan, R.C. Surdam, and R.E. Ewing, The effect of carboxylic acid anions on the stability of framework mineral grains, SPE No. 17802, *Proceedings of 1988 Rocky Mountain Regional Meeting of SPE*, Casper, Wyoming, May 1988, 621–630; and *Proceedings of Fourth Wyoming Enhanced Oil Recovery Symposium*, Casper, Wyoming, May 1988, pp. 71–86.

63. C.P. Angelos and R.E. Ewing, Use of continuous thermodynamic correlations for thermal simulations using a cubic equation of state, *Proceedings of 25th National Heat Transfer Conference*, AIChE Symposium Series, No. 263, Vol. 84, Houston, Texas, July 1988, 186–190.

64. R.F. Ewing, Modern trends in reservoir modeling, *Proceedings of the VISTA Conference on Fundamental Oil and Gas Research*, Stavanger, Norway, June 1-3, 1988, 51-58.

65. T. Lin and R.E. Ewing, A direct numerical method for an inverse problem for the heat equation via hyperbolic perturbation, *Proc. 27th IEEE Conf. on Decision and Control*, Austin, Texas, December 7-9, 1988, Vol. 1, 240-244.

66. R.E. Ewing and T. Lin, A direct method for parameter estimation in a hyperbolic partial differential equation, *Proc. 27th IEEE Conf. on Decision and Control*, Austin, Texas, December 7-9, 1988, Vol. 2, 1662-1667.

67. R.E. Ewing and T. Lin, Parameter identification problems in single-phase and two-phase flow, *Proc. 4th Int. Conf. on Control of Distributed Parameter Systems, International Series for Numerical Mathematics*, Birkhauser Verlag, Basel, 91 (1989), 85-108.

68. T. Lin and R.E. Ewing, A note on source term identification for parabolic equations, *Proc. Fourth International Conference on Control of Distributed Parameter Systems, International Series for Numerical Mathematics*, Birkhauser Verlag, Basel, 91 (1989), 263-281.

69. R.E. Ewing, B.A. Boyett, D.K. Babu, and R.F. Heinemann, Efficient use of locally refined grids for multiphase reservoir simulation, SPE 18413, *Proceedings of Tenth SPE Symposium on Reservoir Simulation*, Houston, Texas, February 6-8, 1989, 55-70.

70. R.E. Ewing, Advances in reservoir simulation techniques for enhanced oil recovery, *Proceedings of Third International Symposium on Enhanced Oil Recovery*, Maracaibo, Venezuela, February 19-27, 1989.

71. R.E. Ewing, Adaptive mesh refinements for transient flow problems, *Finite Element Analysis in Fluids* (T.J. Chung and G.R. Kerr, editors), University of Alabama in Huntsville Press, Huntsville, Alabama, 1989, 119-124.

72. R.E. Ewing, Yirang Yuan, and Gang Li, Finite element methods for chemical-flooding simulation, *Finite Element Analysis in Fluids* (T.J. Chung and G.R. Kerr, editors), University of Alabama in Huntsville Press, Huntsville, Alabama, 1989, 1266-1271.

73. R.E. Ewing, Characteristic Petrov-Galerkin methods for advection-dominated flows, *Finite Element Analysis in Fluids* (T.J. Chung and G.R. Kerr, editors), University of Alabama in Huntsville Press, Huntsville, Alabama, 1989, 959-964.

74. R.E. Ewing, Finite element methods in reservoir simulation, *Finite Element Analysis in Fluids*, (T.J. Chung and G.R. Kerr, eds.), University of Alabama in Huntsville Press, Huntsville, Alabama, 1989, 1251-1257.

75. R.E. Ewing and D.L. Whitman, Laboratory and simulation investigation of increasing the sweep efficiency of CO_2 flooding by utilizing a horizontal injection well, *Proceedings of 1989 AIChE National Meeting*, Houston, Texas, April 1989.

76. R.E. Ewing and T. Lin, Error estimation for determination of unknown coefficients in parabolic equations, *Proceedings of Fifth Symposium on Control of Distributed Parameter Systems of the International Federation of Automatic Control*, Perpignan, France, June 25-29, 1989, 325-330; *Control of Distributed Parameter Systems 1989*, (M. Amouroux and A. El-Jai, eds.), Pergamon Press,

New York, 1989, 203–208.

77. I. Herrera and R.E. Ewing, Localized adjoint methods: application to multiphase flow problems, *Proceedings of the Fifth Wyoming Enhanced Oil Recovery Symposium*, Casper, Wyoming, May 10-11, 1989, 155–173.

78. M.B. Allen and R.E. Ewing, How aquifer heterogeneities affect numerical groundwater models (with M.B. Allen) *Proceedings of Groundwater Engineering and Management Conference*, Denver, Colorado, February 28–March 7, 1990, 161–170.

79. J. Sochacki, P. O'Leary, C. Bennett, R.E. Ewing, and R. Sharpley, Seismic modeling and inversion on the NCUBE, *The Fifth Distributed Memory Computing Conference, Vol. 1*, (D. Walker and Q. Stout, eds.), IEEE Computer Society Press, 1990, 530–535.

80. M.S. Espedal, R. Hansen, P. Langlo, O. Saevareid, and R.E. Ewing, Heterogeneous porous media and domain decomposition methods, *Proceedings of 2nd European Conference on the Mathematics of Oil Recovery*, (D. Guerillot and O. Guillon, eds.), Editors Technip, Paris, 1990, 157–163.

81. M.S. Espedal, R.E. Ewing, and T.F. Russell, Mixed methods, operator splitting, and local refinement techniques for simulation on irregular grids, *Proceedings of 2nd European Conference on the Mathematics of Oil Recovery*, Editors Technip, Paris, 1990, 237–245.

82. R.E. Ewing, Localized phenomena and scale-up in reservoir simulations, *Proceedings of Second World Congress on Computational Mechanics*, Stuttgart, Federal Republic of Germany, August 27–31, 1990, 734–737.

83. J.A. Puckett and R.J. Schmidt, Finite strip method in a parallel computing environment, *Parallel and Distributed Processing in Structural Systems*, ASCE National Convention, Nashville, Tennessee, May 1988, 85–91.

B. ACCEPTED

84. M.S. Espedal, R.E. Ewing, T.F. Russell, and O. Saevareid, Reservoir simulation using mixed methods, a modified method of characteristics, and local grid refinement, *Proceedings of Joint IMA/SPE European Conference on The Mathematics of Oil Recovery*, Robinson College, Cambridge University, July 25–27, 1989, (to appear).

85. R.E. Ewing, R.D. Lazaraov, P. Lu, and P.S. Vassilevski, Preconditioning indefinite systems arising from mixed finite element discretization of second-order elliptic systems, *Proceedings of Conference on Preconditioned Conjugate Gradient Methods*, Nijmegen, The Netherlands, June 15–17, 1989, (to appear).

86. R.E. Ewing, Operator splitting and Eulerian-Lagrangian localized adjoint methods for multiphase flow, *Proceedings of Conference on Mathematics of Finite Elements and Applications (MAFELAP)*, Brunel University, Uxbridge, United Kingdom, (to appear).

87. R.E. Ewing, R.D. Lazarov, and P.S. Vassilevski, Mixed finite element solution of second order elliptic problems on grids with regular local refinement, *Proceedings of 4th International Conference on Domain Decomposition Methods*, Moskow, USSR, May 21–25, 1990, (to appear).

9

88. R.E. Ewing and H. Wang, Eulerian-Lagrangian localized adjoint methods for linear advection equations, *Proceedings of International Conference on Computational Engineering Science*, Patras, Greece, 1991, (to appear).

89. R.E. Ewing, James Sochacki, and Tao Lin, Interface conditions for acoustic wave propagation, *Proceedings of First International Conference on Mathematical and Nume-ical Aspects of Wave Propagation Phenomena*, Strasbourg, France, April 23–26, 1991, (to appear).

References by Investigator:

R.E. Ewing:	1–3, 6, 8–13, 16, 22–34, 40–51, 56–82, 84–89
M.B. Allen, III:	4, 5, 7, 14, 53–55, 78
E.L. Isaacson:	17, 18, 36–39, 52
J.A. Puckett:	1, 19–21, 83
M.M. Stephens:	15, 35